College of Engineering

Civil Engineering Department

Surveying Engineering Program

SE 496

INCREASING THE ACCURACY OF VERTICAL MEASUREMENT IN THE HANDLE GPS FOR RIYADH CITY

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Submitted in Partial Fulfillment of the Requirements for the

B.Sc. Degree in Civil Engineering

15/4/1440, Corresponding to 12/12/2019

Riyadh, Kingdom of Saudi Arabia

Our vision is to be a world-class department in civil engineering through education students, and advancing research and professional practice

We hereby approve the report entitled:

INCREASING THE ACCURACY OF VERTICAL MEASUREMENT IN THE HANDLE GPS FOR RIYADH CITY

Prepared by:

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23/4/2020

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ACKNOWLEDGMENTS:

We are grateful to our supervisors, Prof. Hassan Bilani and Prof. Ismaat Elhassan for their sincere guidance and help during the progress of this project work. Thanks are also extended to members of General Commission for Survey (GCS) and Ministry of Municipal and Rural Affairs (MOMRA) for providing us the valuable information that help us in executing our project.

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ENOTATION & ACRONYMS

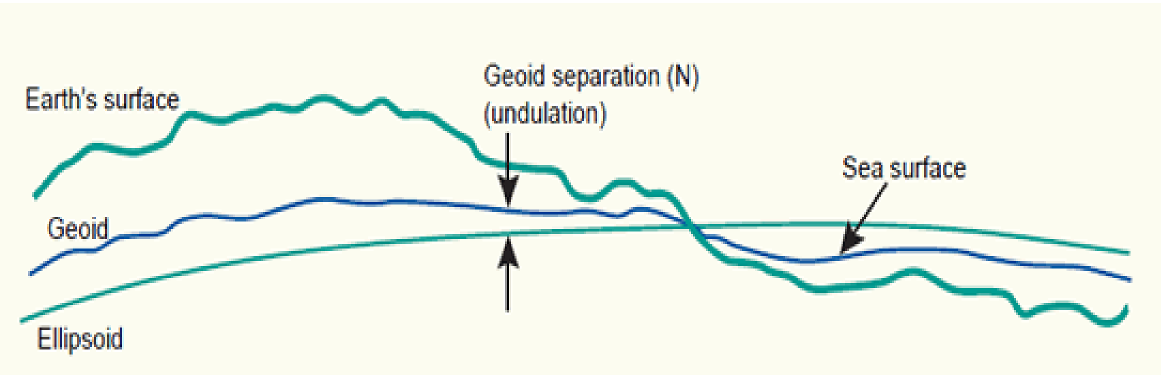
- 1D one dimensional
- 2D two dimensional
- 3D three-dimensional
- ACP Active Control Point
- ACS Active Control System
- Az. azimuth
- c speed of light in a vacuum
- CDU control and display unit
- DoD United States Department of Defense
- DoT United States Department of Transportation
- EDM electronic distance measurement
- Elev. elevation angle
- f frequency
- GDOP geometrical dilution of precision
- GIS geographical information system
- GPS Global Positioning System
- GPSIC Global Positioning System Information Center
- GSD91 Geodetic Survey Division 1991 geoid model
- h ellipsoidal height
- H orthometric height
- HDOP horizontal dilution of precision
- Hz hertz (cycles per second) - unit of measure for frequency
- h^{GPS} the GPS height above the ellipsoid
- IERS International Earth Rotation Service
- ITRF91 IERS Terrestrial Reference Frame
- λ wavelength
- MOMRA Ministry of Municipal and Rural Affairs
- GCS General Commission for Survey
- MHz one million hertz (see Hz)
- MSE mean square error
- N ambiguity, or
- N geoid undulation, or
- $\mathbb{N}$ the geoid separation
-
- NAD27 North American Datum 1927
- NAD83 North American Datum 1983
- NGDB National Geodetic Database (maintained by GSD)
- NGS U.S. National Geodetic Survey
- NTS National Topographic System
- P code measurement
- PDOP positional dilution of precision
- ppm parts per million
- ρ range
- rcvr receiver
- RF radio frequency
- RINEX receiver independent exchange format
- rms root mean square
- σ standard deviation
- SA selective availability
- SEP spherical error probable
- SMRSS Surveys, Mapping and Remote Sensing Sector
- tr reception time
- tt transmission time
- UERE user equivalent range error
- UTM Universal Transverse Mercator Projection
- VDOP vertical dilution of precision
- WGS84 World Geodetic System 1984
- xr,yr,zr receiver coordinates
- xs,ys,zs satellite coordinate

INTRODUCTION & OBJECTIVES

Introduction

Determination of the geoid has been one of the main research areas in geodesy for several decades. More and more accurate geo-potential models have been developed. A vertical reference frame or datum forms the basis for most development projects in which heights are used.

In particular, most of the Geomatic Engineering, surveying, geodetic and geophysics applications are requiring orthometric height (H), height above the geoid, e.g. (Figure 1) because it relates to the Earth's physical surface.



(Figure 1) : The Earth's surface, and two reference surfaces used to approximate it: The Geoid, and a reference ellipsoid.

The GPS survey provides the horizontal and vertical locations of earth features with respect to the Reference Spheroid (the WGS 84).

The vertical locations so provided are known as ellipsoidal heights, However, in civil engineering and geosciences applications such as transportation planning, construction of dams, watershed management etc. the vertical location wanted is usually the orthometric heights popularly known as Mean Sea Level (MSL) height and this is with respect to geoid as the reference surface. Therefore, it is necessary to convert the GPS survey based ellipsoidal heights to geoid based orthometric heights.

This is done by integrating a global or local geoid model with the ellipsoidal heights. There are global geoid models such as EGM 2008 for the purpose which supports the conversion of ellipsoidal heights to orthometric heights with accuracies varying between few centimeters to even a meter.

The accuracy of the conversion may be further improved with adoption of regional or local geoid models.

Objectives

The main objective of this project is to develop a geoid model for Riyadh city to be able to compute orthometric heights H that refer to the national geodetic vertical datum (NGVD) by GPS instrument.

It will save time, effort and money instead of using the traditional leveling to compute the coordinates,

We will use the GPS devices directly to find the approximate height, which can be quickly and accurately, with accuracies varying between few centimeters to even a meter.

Mathematically, there is a relation between the two reference systems (neglecting the deflection of the vertical and the curvature of the plumb line) as the following formula:

$$\mathbf{H = h^{GPS} - N}$$

Where, $\mathbf{h^{GPS}}$ is the GPS height above the ellipsoid and **N** the geoid separation e.g. (Figure 1). In the above equation it is important to realize that **H** refers to a local vertical datum,

$\mathbf{h^{GPS}}$ refers to a geocentric system (ITRF/ WGS84), to which the computed (gravimetric) geoid also usually refers.

In practice, the expression shows the possibility of using GPS leveling technique, knowing the separation **N**, the orthometric height **H** can be calculated from ellipsoidal height **h**.

Deriving orthometric height using this technique with certain level of accuracy, could replace conventional spirit leveling and therefore make the levelling procedures cheaper and faster.

The existence of datum bias (differences between geoid and local mean sea level) will not give satisfactory results if based on the above formula.

In order to overcome this problem, fitting the gravimetric geoid onto the local mean sea level (NGVD) will minimize the effect of datum biases.

If this process succeeds, it will be helping to avoid some of the problems and obstacles that companies face in some civil and non-civil engineering projects such as military uses and navigation.

Project goals:

1- Create a mathematical model and applying it in the handheld GPS .
2- Increasing the accuracy of Vertical measurement in the handle GPS .

Project problem and importance:

1- The control points are so many and far away because Riyadh city has a huge area .
2- Some control points located in critical area or it out of serves .
3- General Commission for Survey (GCS) and Ministry of Municipal and Rural Affairs (MOMRA)'s points may not be connected to each other or not having the same corrodents .

We faced problems to do our graduation project :

1- Corona virus paradise .
2- home quarantine .
3- non-mobility.
4- The Ministry was late in handing over the points.

Literature Review:

Here some of the researches that we have seen and we found it helpful and revolves around our Idea:-

1- GPS signal accuracy and coverage analysis platform: Application to Trimble Juno SB receiver

Researchers: Abdellah El Abbous , El Adib Samir and Naoufal Raissouni (Abdelmalek Essaâdi University , Tétouan, Tetouan , Morocco)

This project examines the use of GPS and creating a model for increasing the accuracy the measurement of the corrodents

- We both study the relationship between GPS and Geodesy .
- We both have control points but different region .
- We will use RTK GPS to help us and increasing the accuracy the measurement of the corrodents . On the other hand , they use STAIC GPS
- We have more than 300 points , 9 check points and 110 points to measure . Whereas , they have only 100 points and no check points at all .

2- On the (In-)Accuracy of GPS Measures of Smartphones: A Study of Running Tracking Applications

Researchers: Christine Bauer (Johannes Kepler University Linz)

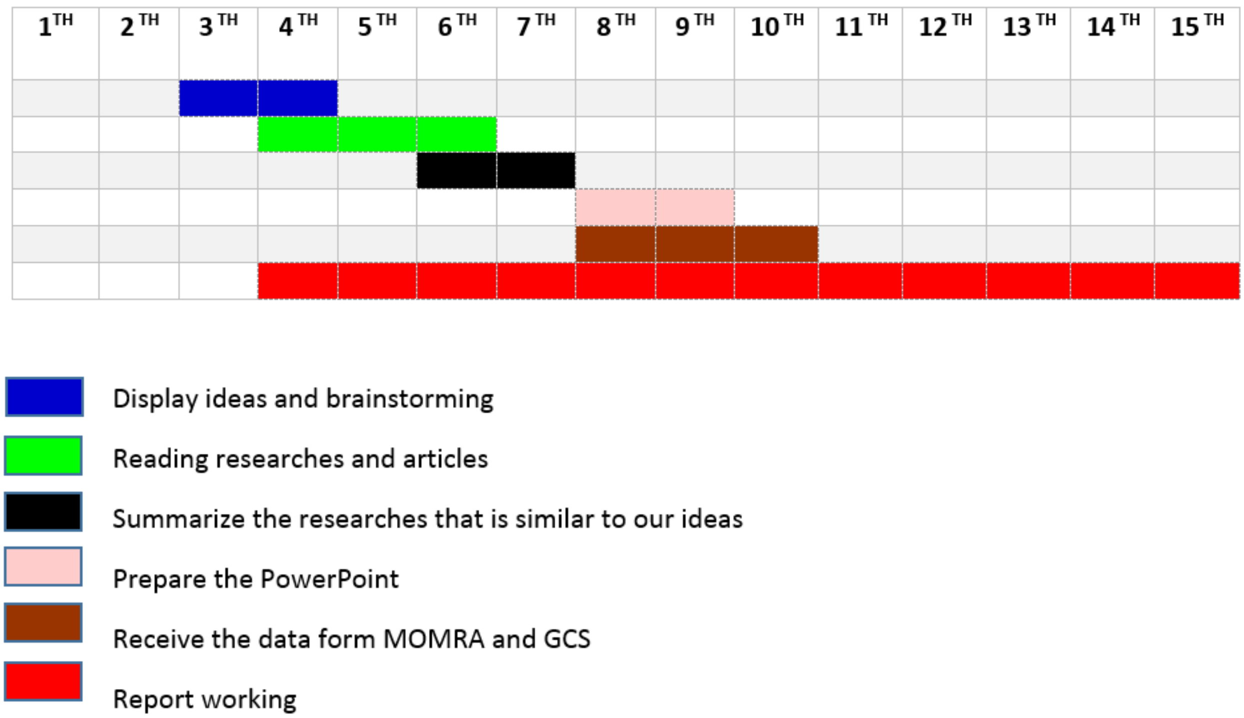
This project examines the use of GPS and creating a model for increasing the accuracy the measurement of the corrodents

- We both study the relationship between GPS and Geodesy .
- She deal with smart phones and application , but we will use the handheld GPS .
- Her title goes around tracking but our title is about the corrodents .

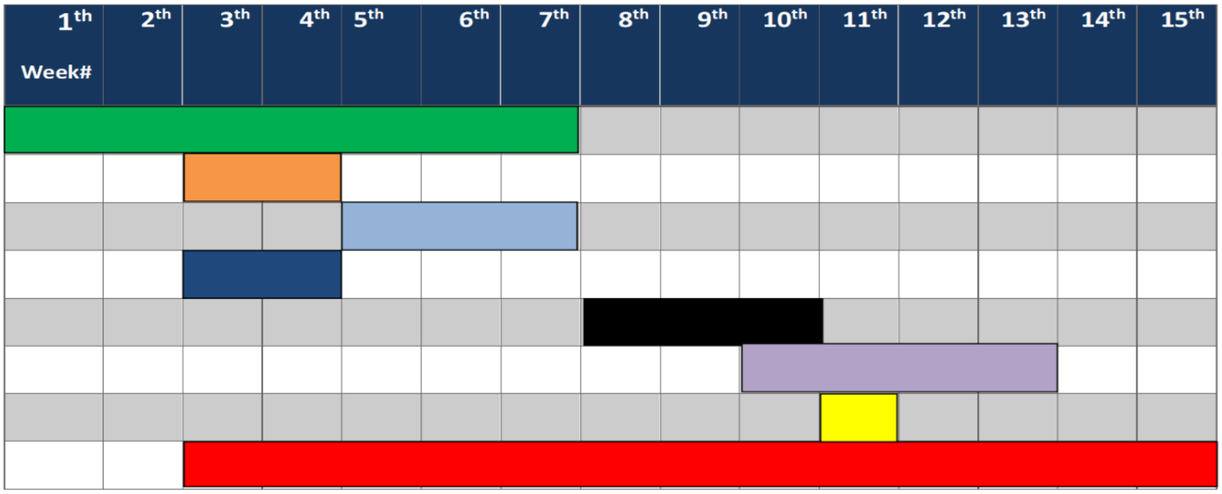
Time line :

planning can be considered as one of the key reasons behind the goal achievement, Goals are achieved after the execution of the plan, so this is our project plan (time line) for the first term and second term project :

1st term :



2ed term :



- Collecting the data
- Analyzing the data
- Points distribution
- Visit the MOMRA
- Visit the points
- No work
- Calculations and results
- Report working

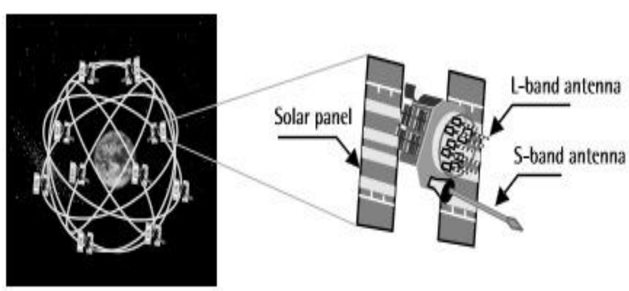
Chapter 1

GPS

The Global Positioning System (GPS) is a satellite-based navigation system that was developed by the U.S. Department of Defense (DoD) in the early 1970s. Initially, GPS was developed as a military system to fulfill U.S. military needs. However, it was later made available to civilians, and is now a dual-use system that can be accessed by both military and civilian users [1]. GPS provides continuous positioning and timing information, anywhere in the world under any weather conditions. Because it serves an unlimited number of users as well as being used for security reasons , GPS is a one-way-ranging (passive) system [2]. That is, users can only receive the satellite signals. This chapter introduces the GPS system, its components, and its basic idea.

1.1Overview of GPS

GPS consists , nominally , of a constellation of 24 operational satellites . This constellation, known as the initial operational capability (IOC), was completed in July 1993. The official IOC announcement, however, was made on December 8, 1993 [3]. To ensure continuous worldwide coverage, GPS satellites are arranged so that four satellites are placed in each of six orbital planes (Figure 2).



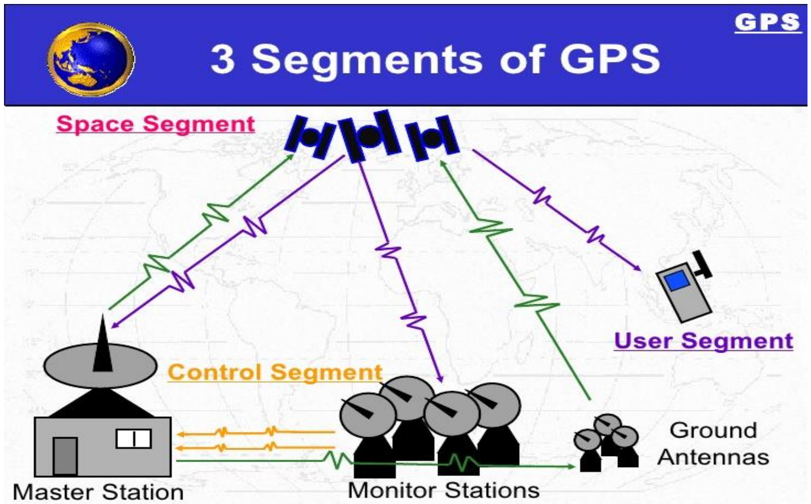
(Figure 2) : Overview of GPS

With this constellation geometry, four to ten GPS satellites will be visible anywhere in the world, if an elevation angle of 10° is considered .As discussed later , only four satellites are needed to provide the positioning, or location, information. GPS satellite orbits are nearly circular (an elliptical shape with a maximum eccentricity is about 0.01), with an inclination of about 55° to the equator . These major axis of a GPS orbits about 26,560 km (i.e. , the satellite altitude of about 20,200 km above the Earth \ surface) [4] .

The corresponding GPS orbital period is about 12 sidereal hours (~11 hours, 58 minutes). The GPS system was officially declared to have achieved full operational capability (FOC) on July 17, 1995, ensuring the availability of at least 24 operational ,non experimental ,GPS satellites . In fact , as shown in Section 1.4 , since GPS achieved its FOC , the number of satellites in the GPS constellation has always been more than 24 operational satellites.

1.2 GPS segments

GPS consists of three segments (Figure 3) :

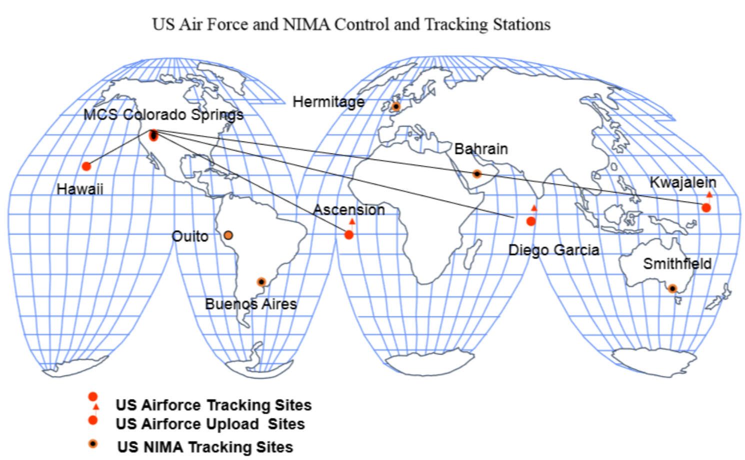


(Figure 3) : GPS segments

1- Space Segment: satellite constellation (28 active satellites in space).

2- Control Segment: five ground stations located on earth. (Figure 4)

3- User Segment: GPS receiver units that receive satellite signals and determine receiver location from them. [5].



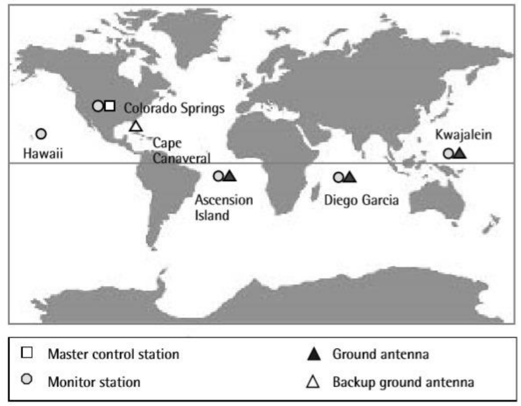
(Figure 4) : Control Segment

The space segment consists of the 24-satellite constellation in traduced in the previous section . Each GPS satellite transmits a signal, which has a number of components: two sine waves (also known as carrier frequencies), two digital codes, and a navigation message .The codes and the navigation message are added to the carriers as binary biphase modulations [5]. The carriers and the codes are used mainly to determine the distance from the users receiver to the GPS satellites. The navigation message contains, along with other information, the coordinates (the location) of the satellites as a function of time. The transmitted signals are controlled by highly accurate atomic clocks onboard the satellites. More about the GPS signal is given in Chapter 2. The control segment of the GPS system consists of a worldwide network of tracking stations, with a master control station (MCS) located in the United States at Colorado Springs, Colorado. The primary task of the operational control segment is tracking the GPS satellites in order to determine and predict satellite locations, system integrity, behavior of the satellite atomic clocks, atmospheric data, the satellite almanac, and other considerations. This information is then packed and uploaded into the GPS satellites through the S-band link. The user segment includes all military and civilian users. With a GPS receiver connected to a GPS antenna, a user can receive the GPS signals, which can be used to determine his or her position any where in the world. GPS is currently available to all users worldwide at no direct charge.

1.3 Control sites

The control segment of GPS consists of

1- a master control station (MCS)
2- a worldwide network of monitor stations
3- ground control stations (Figure 5).



(Figure 5) : Control sites

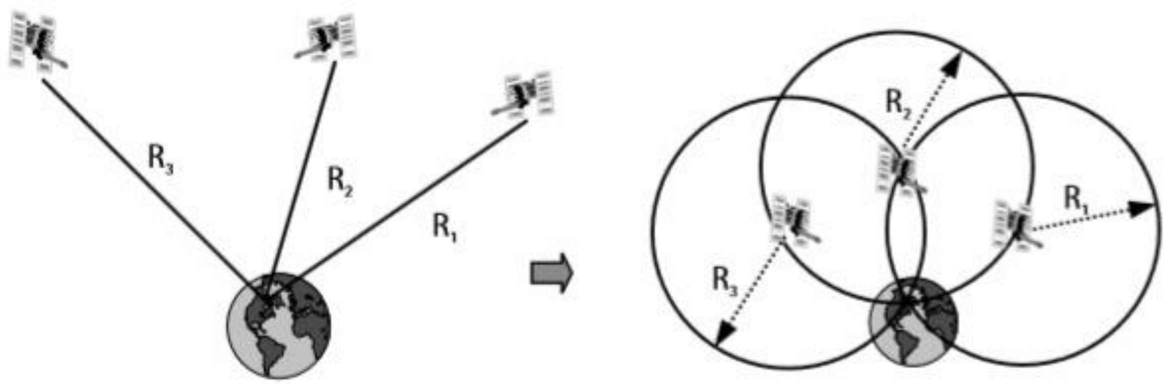
The MCS, located near Colorado Springs, Colorado, is the central processing facility of the control segment and is manned at all times [9]. There are five monitor stations, located in Colorado Springs (with the MCS), Hawaii, Kwajalein, Diego Garcia, and Ascension Island. The positions (or coordinates) of these monitor stations are known very precisely.

Each monitor station is equipped with high-quality GPS receivers and a cesium oscillator for the purpose of continuous tracking of all the GPS satellites in view . Three of the monitor stations (Kwajalein, Diego Garcia, and Ascension Island) are also equipped with ground antennas for uploading the information to the GPS satellites. All of the monitor stations and the ground control stations are unmanned and operated remotely from the MCS. The GPS observations collected at the monitor stations are transmitted to the MCS for processing. The outcome of the processing is predicted satellite navigation data that includes, along with other information, the satellite positions as a function of time, the satellite clock parameters, atmospheric data, satellite almanac, and others. This fresh navigation data is sent to one of the ground control stations to upload it to the GPS satellites through the S-band link.

Monitoring the GPS system integrity is also one of the tasks of the MCS. The status of a satellite is set to unhealthy condition by the MCS during satellite maintenance or outages. This satellite health condition appears as a part of the satellite navigation message on a near real-time basis. Scheduled satellite maintenance or outage is reported in a message called Notice Advisory to Navstar Users (NANU), which is available to the public through, for example, the U.S. Coast Guard Navigation Center [8].

1.4 The basic idea

The idea behind GPS is rather simple. If the distances from a point on the Earth (a GPS receiver)to three GPS satellites are known along with the satellite locations, then the location of the point (or receiver) can be determined by simply applying the well-known concept of resection [10]. That is all ! But how can we get the distances to the satellites as well as the satellite locations? As mentioned before, each GPS satellite continuously transmits a microwave radio signal composed of two carriers ,two codes , and a navigation message. When a GPS receiver is switched on, it will pick up the GPS signal through the receiver antenna. Once the receiver acquires the GPS signal, it will process it using its built-in software. The partial outcome of the signal processing consists of the distances to the GPS satellites through the digital codes (known as the pseudo ranges) and the satellite coordinates through the navigation message. Theoretically , only three distances to three simultaneously tracked satellites are needed . In this case , the receiver would be located at the intersection of three spheres ; each has a radius of one receiver-satellite distance and is centered on that particular satellite (Figure 6) .From the practical point of view, however, a fourth satellite is needed to account for the receiver clock offset [6].



(Figure 6) : The basic idea of GPS

1.5 GPS positioning service

As stated earlier ,GPS was originally developed as a military system ,but was later made available to civilians as well. However, to keep the military advantage , the U.S.DoD provides two levels of GPS positioning and timing services: the Precise Positioning Service (PPS) and the Standard Positioning Service (SPS) [3].

PPS is the most precise autonomous positioning and timing service. It uses one of the transmitted GPS codes, known as P(Y)-code, which is accessible by authorized users only. These users include U.S. military forces. The expected positioning accuracy provided by the PPS is 16m for the horizontal component and 23m for the vertical component (95% probability level). SPS, however, is less precise than PPS. It uses the second transmitted GPS code, known as the C/A-code, which is available free of charge to all users worldwide, authorized and unauthorized. Originally, SPS provided positioning accuracy of the order of 100m for the horizontal component and 156m for the vertical component (95% probability level). This was achieved under the effect of selective availability . With the recent presidential decision of discontinuing the SA, the SPS autonomous positioning accuracy is presently at a comparable level to that of the PPS.

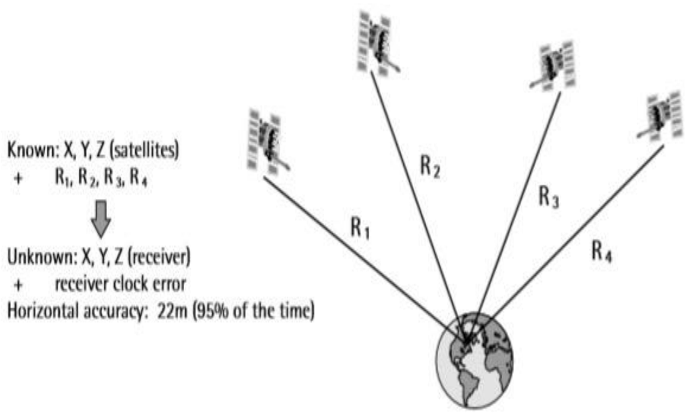
Chapter 2

GPS Positioning Modes

Positioning with GPS can be performed by either of two ways: point positioning or relative positioning. GPS point positioning employs one GPS receiver that measures the code pseudo ranges to determine the users position instantaneously, as long as four or more satellites are visible at the receiver. The expected horizontal positioning accuracy from the civilian C/A-code receivers has gone down from about 100 m (2 drms) when selective availability was on, to about 22m (2 drms) in the absence of selective availability [1]. GPS point positioning is used mainly when a relatively low accuracy is required. This includes recreation applications and low accuracy navigation. GPS relative positioning, however, employs two GPS receivers simultaneously tracking the same satellites. If both receivers track at least four common satellites, a positioning accuracy level of the order of a sub-centimeter to a few meters can be obtained [2]. Carrier-phase or/and pseud orange measurements can be used in GPS relative positioning , depending on the accuracy requirements. The former provides the highest possible accuracy . GPS relative positioning can be made in either real-time or post mission modes . GPS relative positioning is used for high-accuracy applications such as surveying and mapping, GIS, and precise navigation.

2.1 GPS point positioning

GPS point positioning ,also known as stand alone or autonomous positioning, involves only one GPS receiver. That is, one GPS receiver simultaneously tracks four or more GPS satellites to determine its own coordinates with respect to the center of the Earth (Figure 7).



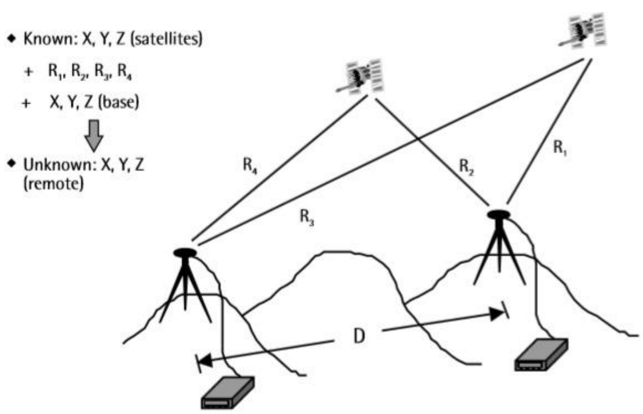
(Figure 7) : GPS point positioning

Almost all of the GPS receivers currently available on the market are capable of displaying their point-positioning coordinates. To determine the receivers point position at any time, the satellite coordinates as well as a minimum of four ranges to four satellites are required[2] . The receiver gets the satellite coordinates through the navigation message, while the ranges are obtained from either the C/A-code or the P(Y)-code, depending on the receiver type (civilian or military). As mentioned before, the measured pseudo ranges are contaminated by both the satellite and receiver clock synchronization errors . Correcting the satellite clock errors may be done by applying the satellite clock correction in the navigation message; the receiver clock error is treated as an additional unknown parameter in the estimation process [2]. This brings the total number of unknown parameters to four : three for the receiver coordinates and one for the receiver clock error . This is the reason

why at least four satellites are needed. It should be pointed out that if more than four satellites are tracked , the so-called least-squares estimation or Kalman filtering technique is applied . As the satellite coordinates are given in the WGS 84 system, the obtained receiver coordinates will be in the WGS 84 system . however, most GPS receivers provide the transformation parameters between WGS 84 and many local datums used around the world.

2.2 GPS relative positioning

GPS relative positioning, also called differential positioning, employs two GPS receivers simultaneously tracking the same satellites to determine their relative coordinates (Figure 8).



(Figure 8) : GPS relative positioning

Of the two receivers, one is selected as a reference, or base, which remains stationary at a site with precisely known coordinates. The other receiver, known as the rover or remote receiver, has its coordinates unknown. The rover receiver may or may not be stationary, depending on the type of the GPS operation. A minimum of four common satellites is required for relative positioning. However, tracking more than four common satellites simultaneously would improve the precision of the GPS position solution [2]. Carrier phase and/or pseudo range measurements can be used in relative positioning. A variety of positioning techniques are used to

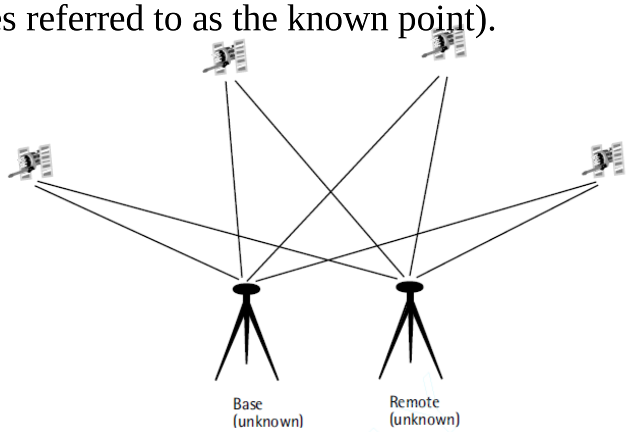
provide a post processing (post mission) or real-time solution. Details of the commonly used relative positioning techniques are given in Sections (2.3 to 2.7) .

GPS relative positioning provides a higher accuracy than that of autonomous positioning. Depending on whether the carrier-phase or the pseudo range measurements are used in relative positioning , an accuracy level of a sub-centimeter to a few meters can be obtained .

This is mainly because the measurements of two (or more) receivers simultaneously tracking a particular satellite contain more or less the same errors and biases [5]. The shorter the distance between the two receivers , the more similar the errors. Therefore, if we take the difference between the measurements of the two receivers (hence the name differential positioning), the similar errors will be removed or reduced.

2.3 Static GPS surveying

Static GPS surveying is a relative positioning technique that depends on the carrier-phase measurements [2]. It employs two (or more) stationary receivers simultaneously tracking the same satellites (see Figure 9). One receiver, the base receiver, is set up over a point with precisely known coordinates such as a survey monument (sometimes referred to as the known point).



(Figure 9) : Static GPS surveying

The other receiver, the remote receiver, is set up over a point whose coordinates are sought (sometimes referred to as the unknown point). The base receiver can support any number of remote receivers, as long as a minimum of four common satellites is visible at both the base and the remote sites.

In principle, this method is based on collecting simultaneous measurements at both the base and remote receivers for a certain period of time, which, after processing, yield the coordinates of the unknown point. The observation, or occupation, time varies from about 20 minutes to a few hours, depending on the distance between the base and the remote receivers (i.e., the baseline length), the number of visible satellites, and the satellite geometry. The measurements are usually taken at a recording interval of 15 or 20 seconds, or one sample measurement every 15 or 20 seconds.

After completing the field measurements, the collected data is downloaded from the receivers into the PC for processing. Different processing options may be selected depending on the user requirements, the baseline length, and other factors. For example, if the baseline is relatively short, say, 15 or 20 km, resolving the ambiguity parameters would be a key issue to ensure high-precision positioning. As such, in this case the option of fixing the ambiguity parameters should be selected. In contrast, if the baseline is relatively long, a user may select the ionosphere-free linear combination option to remove the majority of the ionospheric error. This is because the ambiguity parameters may not be fixed reliably at the correct integer values. For very long baselines, for example, over 1,000 km, it is recommended that the user processes the data with one of the scientific software packages available, such as the BERENSE software developed by the University of Bern, rather than a commercial software package.

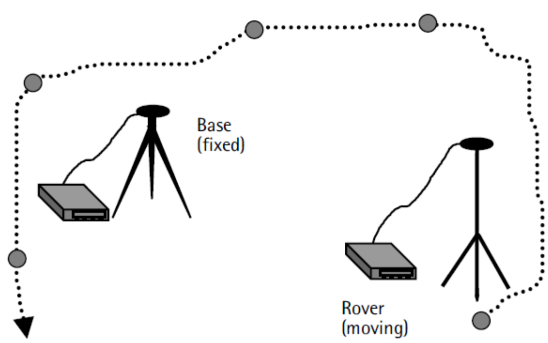
The precise ephemeris should also be used in this case, as the effect of the orbital errors will be considerably different at the two ends of the baseline.

Static GPS surveying with the carrier-phase measurements is the most accurate positioning technique. This is mainly due to the significant change in satellite geometry over the long observation time span. Although both the single- and dual-frequency receivers can be used for static positioning, the latter is often used, especially for baselines exceeding 20 km.

The expected accuracy from a geodetic quality receiver is typically
5 mm + 1 ppm (rms), ppm for parts per million and rms for root-mean-square. That is, for a 10-km baseline, for example, the expected accuracy of the static GPS surveying is 1.5 cm (rms). Higher accuracy may be obtained by, for example, applying the precise ephemeris.

2.4 Fast (rapid) static

Fast, or rapid, static surveying is a carrier-phase. based relative positioning technique similar to static GPS surveying. That is, it employs two or more receivers simultaneously tracking the same satellites. However, with rapid static surveying, only the base receiver remains stationary over the known point during the entire observation session (see Figure 10).



(Figure 10) : Fast (rapid) static

The rover receiver remains stationary over the unknown point for a short period of time only, and then moves to another point whose coordinates are sought [2].

Similar to the static GPS surveying, the base receiver can support any number of rovers.

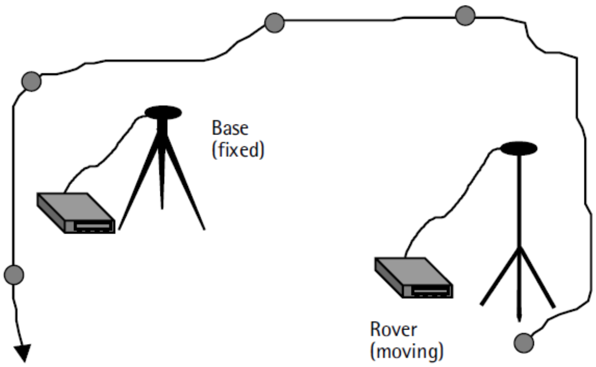
This method is suitable when the survey involves a number of unknown points located in the vicinity (i.e., within up to about 15 km) of a known point. The survey starts by setting up the base receiver over the known point, while setting up the rover receiver over the first unknown point (Figure 10). The base receiver remains stationary and collects data continuously. The rover receiver collects data for a period of about 2 to 10 minutes, depending on the distance to the base as well as the satellite geometry [2]. Once the rover receiver has collected the data, the user moves to the following point with unknown coordinates and repeats the procedures.

It should be pointed out that, while moving, the rover receiver may be turned off. Due to the relatively short occupation time for the rover receiver, the recording interval is reduced to 5 seconds. After collecting and downloading the field data from both receivers, the PC software is used for data processing. Depending on whether enough common data was collected, the software may output a fixed solution, which indicates that the ambiguity parameters were fixed at integer values .

Otherwise, a float solution is obtained, which means that the software was unable to fix ambiguity parameters at integer values (i.e., only real-valued ambiguity parameters were obtained). This problem occurs mainly when the collected GPS data is insufficient. A fixed solution means that the positioning accuracy is at the centimeter level, while the float solution means that the positioning accuracy is at the decimeter or submeter level. Although both the single- and dual-frequency receivers can be used for fast static surveying, the probability of getting a fixed solution is higher with the latter.

2.5 Stop-and-go GPS surveying

Stop-and-go surveying is another carrier-phase-based relative positioning technique. It also employs two or more GPS receivers simultaneously tracking the same satellites (Figure 11):



(Figure 11) : Stop-and-go GPS surveying

a base receiver that remains stationary over the known point and one or more rover receivers.

The rover receiver travels between the unknown points, and makes a brief stop at each point to collect the GPS data. The data is usually collected at a 1- to 2-seconds recording rate for a period of about 30 seconds per each stop.

Similar to the previous methods, the base receiver can support any number of rovers. This method is suitable when the survey involves a large number of unknown points located in the vicinity (i.e., within up to 10.15 km) of a known point. The survey starts by first determining the initial integer ambiguity parameters, a process known as receiver initialization. This could be done by various methods, discussed in the next chapter.

Once the initialization is performed successfully, centimeter-level positioning accuracy can be obtained instantaneously. This is true as long as there is a minimum of four common satellites simultaneously tracked by both the base and

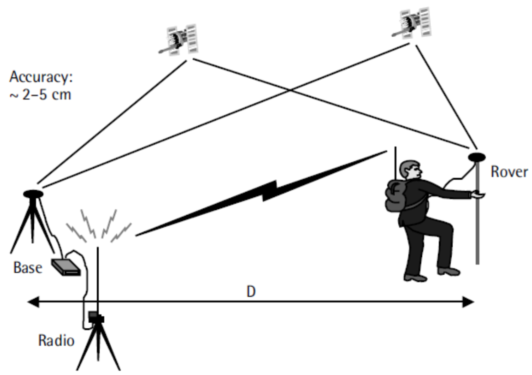
the rover receivers at all times. If this condition is not fulfilled at any moment during the survey, the initialization process must be repeated to ensure centimeter-level accuracy.

Following the initialization, the rover moves to the first unknown point. After collecting about 30 seconds of data, the rover moves, without being switched off, to the second point and the procedures are repeated. It is of utmost importance that at least four satellites are tracked, even during the move; otherwise the initialization process must be repeated again by, for example, reoccupying the previous point. Some manufacturers, for example, Ashtech Inc., recommend the reoccupation of the first point at the end of the survey. This turned out to be very useful in obtaining a fixed solution provided that the processing software has the forward and backward processing functions. Once the data is collected and downloaded, PC software is used to process it. Some software packages have the forward and backward processing functions, which help in obtaining a fixed solution, or centimeter-level accuracy. Both single- and dual-frequency receivers may use the stop-and-go surveying method.

A special case of stop-and-go surveying is known as kinematic GPS surveying. Both methods are the same in principle; however, the latter requires no stops at the unknown points. The positional accuracy is expected to be higher with the stop-and-go surveying, as the errors are averaged out when the receiver stops at the unknown points.

2.6 RTK GPS

RTK surveying is a carrier phase . based relative positioning technique that, like the previous methods, employs two (or more) receivers simultaneously tracking the same satellites (Figure 12).



(Figure 12) : RTK GPS

This method is suitable when:

(1) the survey involves a large number of unknown points located in the vicinity (i.e., within up to about 10.15 km) of a known point.

(2) the coordinates of the unknown points are required in real time.

(3) the line of sight, the propagation path, is relatively unobstructed [6].

Because of its ease of use as well as its capability to determine the coordinates in real time, this method is the preferred method by many users.

In this method, the base receiver remains stationary over the known point and is attached to a radio transmitter (Figure 12). The rover receiver is normally carried in a backpack and is attached to a radio receiver.

Similar to the conventional kinematic GPS method, a data rate as high as 1 Hz (one sample per second) is required. The base receiver measurements and coordinates are transmitted to the rover receiver through the communication (radio) link [7, 8].

The built-in software in a rover receiver combines and processes the GPS measurements collected at both the base and the rover receivers to obtain the rover coordinates.

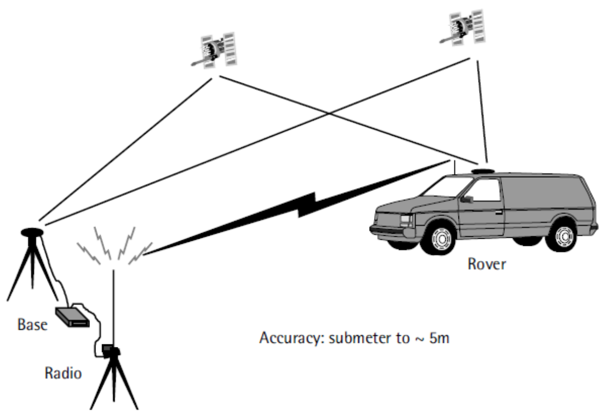
The initial ambiguity parameters are determined almost instantaneously using a technique called on-the-fly (OTF) ambiguity resolution.

Once the ambiguity parameters are fixed to integer values, the receiver (or its handheld computer controller) will display the rover coordinates right in the field. That is, no postprocessing is required. The expected positioning accuracy is of the order of 2 to 5 cm (rms). This can be improved by staying over the point for a short period of time, for example, about 30 seconds, to allow for averaging the position. The computed rover coordinates for the entire survey may be stored and downloaded at a later time into CAD software for further analysis. This method is used mainly, but not exclusively, with dual-frequency receivers.

Under the same conditions, the positioning accuracy of the RTK method is slightly degraded compared with that of the conventional kinematic GPS method. This is mainly because the time tags (or time stamps) of the conventional kinematic data from both the base and the rover match perfectly in the processing. With RTK, however, the base receiver data reaches the rover after some delay (or latency). Data latency occurs as a result of formatting, packetizing, transmitting, and decoding the base data [7]. To match the time tag of the rover data, the base data must be extrapolated, which degrades the positioning accuracy.

2.7 Real-time differential GPS

Real-time differential GPS (DGPS) is a code-based relative positioning technique that employs two or more receivers simultaneously tracking the same satellites (Figure 13).



(Figure 13) : Real-time differential GPS

It is used when a real-time meter-level accuracy is enough. The method is based on the fact that the GPS errors in the measured Pseudo ranges are essentially the same at both the base and the rover, as long as the baseline length is within a few hundred kilometers.

As before, the base receiver remains stationary over the known point.

The built-in software in the base receiver uses the precisely known base coordinates as well as the satellite coordinates, derived from the navigation message, to compute the ranges to each satellite in view. The software further takes the difference between the computed ranges and the measured code pseudo ranges to obtain the pseudo range errors (or DGPS corrections). These corrections are transmitted in a standard format called Radio Technical Commission for Maritime Service (RTCM) to the rover through a communication link (see Chapter 8 for more about RTCM). The rover then applies the DGPS

corrections to correct the measured pseudo ranges at the rover. Finally, the corrected pseudo ranges are used to compute the rover coordinates.

The accuracy obtained with this method varies between a submeter and about 5m, depending on the base-rover distance, the transmission rate of the RTCM DGPS corrections, and the performance of the C/A-code receivers [2]. Higher accuracy is obtained with short base-rover separation, high transmission rate, and carrier-smoothed C/A-code ranges. With the termination of selective availability, the data rate could be reduced to 10 seconds or lower without noticeable accuracy degradation.

Further accuracy improvement could be achieved if the receivers are capable of storing the raw pseudo range measurements, which could be used at a later time in the post processing mode. As the real-time DGPS is widely used, some governmental agencies as well as private firms are providing the RTCM DGPS corrections either at no cost or at certain fees.

2.8 GPS APPLICATIONS

Using the Global Positioning System (GPS, a process used to establish a position at any point on the globe) the following two values can be determined anywhere on Earth:

• One's exact location (longitude, latitude and height co-ordinates) accurate to within a range of 20 m to approx. 1mm

• The precise time (world time, Universal Time Coordinated, UTC) accurate to within a range of 60ns to approx. 1ns.

Various additional variables can be derived from the three-dimensional position and the exact time, such as:

• speed
• acceleration
• course
• local time
• range measurements

The traditional fields of application for GPS are surveying, shipping and aviation. However, the market is currently enjoying a surge in demand for electronic car navigation systems. The reason for this enormous growth in demand is the motor industry, which is hoping to make better use of the road traffic network by utilising this equipment. Applications, such as Automatic Vehicle Location (AVL) and the management of vehicle fleets also appear to be on the rise. GPS is also being increasingly utilised in communication technology. For example, the precise GPS time signal is used to synchronise telecommunications networks around the world. From 2001, the US Federal Communications Commission

(FCC) is demanding that, when Americans ring 911 in an emergency, their position can automatically be located to within approx. 125m. This law, known as E-911 (Enhanced 911), means that mobile telephones will have to be upgraded with this new technology.

In the leisure industry too, the use of GPS is becoming increasingly established. Whether on a hike, out hunting, touring on one's Mountain Bike, or surfing across Lake Constance in Southern Germany, a GPS receiver provides good service in any location.

Basically, GPS can be used anywhere where satellite signal reception is possible. GPS has readily found itself a place in archaeology ever since this branch of science began to use aerial and satellite imaging. By combining GIS (Geographic Information Systems) with satellite and aerial photography, as well as GPS and 3D modelling, it has been possible to answer some of the following questions.

• What conclusions regarding the distribution of cultures can be made based on finds?

• Is there a correlation between areas favouring the growth of certain arable plants and the spread of certain cultures?

• What sort of blending and intermingling of attributes enable conclusions to be drawn regarding the probable furthest most extent of a culture?

• What did the landscape look like in this vicinity 2000 years ago?

Geometricians use (D)GPS, in order to carry out surveys (satellite geodesy) quickly and efficiently to within an accuracy of a millimeter. For geometricians, the introduction of satellite-based surveying represents a

quantum leap comparable to that between the abacus and the computer. The applications are endless, ranging from surveying properties, streets, railway lines and rivers to even charting the ocean depths, conducting Land Register surveys, carrying out deformation measurements and monitoring landslides etc.

In land surveying, GPS has virtually become an exclusive method for pinpointing sites in basic networks.

Everywhere around the world, continental and national GPS networks are emerging that, in conjunction with the global ITRF, provide homogenous and highly accurate networks of points for density and point to point measurements. At a regional level, the number of tenders to set up GPS networks as a basis for geo-information systems and cadastral land surveys is growing.

Already today, GPS has an established place in photogrammetry.

Apart from determining co-ordinates for ground reference points, GPS is regularly used to determine aerial survey navigation and camera co-ordinates in aero-triangulation. Using this method, over 90% or so of ground reference points can be dispensed with. Future remote reconnaissance satellites will also have GPS receivers, so that the evaluation of data for the production and updating of maps in underdeveloped countries, is made easier.

In hydrography, GPS can be used to determine the exact height of the survey boat, in order to facilitate the arrangement of vertical measurements on a clearly defined height reference surface. The expectation is that operational methods in this field will be available in the near future.

Other possible areas of application for GPS are:

- Archaeology
- Seismology (geophysics)
- Glaciology (geophysics)
- Geology (mapping)
- Surveying deposits (mineralogy, geology)
- Physics (flow measurements, time standardisation measurement)
- Scientific expeditions
- Engineering sciences (e.g. shipbuilding, general construction industry)
- Cartography
- Geography
- Geo-information technology
- Forestry and agricultural sciences
- Landscape ecology
- Geodesy
- Aerospace sciences

The most crucial application of GPS is in survey purview .

- GPS in Surveying, Mapping, and Geographical Information

Systems

For several reasons, GPS receiver technology owes much to its early application in the business of land surveying. The production of maps and charts and the georeferencing of data using GPS are natural outgrowths of the accurate and reliable techniques developed for the land-survey market.

    - Surveying

The huge economic advantage of using GPS in surveying applications drove the development of very sophisticated GPS equipment and tools to predict GPS coverage and derive position with centimeter accuracy. Delays in the launch of GPS satellites caused by the Challenger disaster in 1986 further strengthened the head start that surveying applications got over navigational uses of the system, and significant refinements in the use of carrier-phase, dual-frequency, postprocessed, differential positions were made. Extreme accuracy is possible by applying information on satellite positions available after the fact to the data obtained in the field. The value of the technology in the surveying business stems from the availability of absolute positions with respect to a universal coordinate system (WGS-84) and from the fact that they can be determined with a much smaller survey crew. A single surveyor can collect data in the field, where it would take a two- or three-person crew to achieve the same results using some conventional methods. Collected data can be processed to the required accuracy using inexpensive computing facilities, and the GPS equipment in the field can be used by the surveyor for rough surveys or the location of benchmarks or other features. Differential and kinematic techniques can provide accurate real-time information in the field and obviate the need for postprocessing the data, further reducing the cost of surveying operations. A great deal of sophistication has been brought to

products in this area, and to a large extent the market is mature, with a handful of suppliers well entrenched. While the market for simple surveying by GPS may well be saturated, the use of GPS as an aid for position-based data collection for geographical information systems (GIS) continues to fuel growth in the market for sophisticated receivers.

- Mapping

A major early implementation of GPS was in the provision of ground truthing, or orientation of aerial photogrammetry. Aircraft or spacecraft are used to photograph large areas of the Earth's surface. Index marks are often surveyed on the ground to provide reference locations on these photographs, which can be used in determining their scale and orientation. GPS can be used to survey these references. Further, the use of these references can be eliminated altogether if the position of the camera can be known accurately enough at the precise moment it took the picture. This technology has been developed using GPS augmented by accurate INS. Inertial systems have excellent short-term stability but tend to drift over time and require recalibration. By contrast, GPS has its inherent absolute referencing capabilities and can provide excellent augmentation for an INS. The two can be used together in this kind of application; the INS to help resolve cycle ambiguities inherent in the kinematic method of GPS use and to carry positioning duties over the short periods of GPS outage
that may occur. The generation of road maps, or any other kind of feature map, is now extremely easy, achieved simply by recording a series of positions as a receiver is moved over the area to be mapped. Any degree of postprocessing necessary to achieve desired accuracy is available. Specific locations recorded may be annotated with location-specific information, such as street address, elevation, or vegetation type. This type of data collection is particularly useful for the building of data for GIS.

- GIS

Anyone charged with the responsibility of managing a distributed inventory, such as might be the case with a utility, municipality, or steelyard, might appreciate the ability to locate and identify this inventory quickly and accurately. This is the role played by GPS in conjunction with GIS. The last decade has seen a proliferation of GIS software packages and programs. Government agencies and utilities have been eager to adopt this technology, but find that the initial input of data and timely updating thereof is a huge task using conventional means of data collection. With GPS, it is possible to capture position-referenced data in the field with a simple handheld computer. The situation is best illustrated by the example of the management of a municipality’s streetlights. There may be a mix of fluorescent, sodium, mercury, and incandescent lights, with several varieties of each. The maintenance engineer capable of recognizing the types can be dispatched with a GPS-based data collector to log the location of each type of installation. This information can be loaded into a central database, so that when maintenance is necessary, the appropriate replacements can be ordered, stocked, and dispatched. Steel mills store large quantities of product in huge yards, stacked in such a way as to prevent warping.

The stacks must be rotated periodically, on a set schedule. Further, there are different types of products that are indistinguishable from one another, except for the record of where each was put. The layout of these yards does not lend itself to physical marking, so accurate GPS can be used to locate each stack and reference its contents to a central database. The management of other yard inventory items such as shipping containers or lumber is similar, and GPS applications have been investigated here also.

A rapidly growing and highly visible endeavor is the management of natural

resources. Environmental impact studies involve the collection of large amounts of position-related data, and GIS is prevalent here, too. GPS is instrumental in collecting data to provide input to animal population studies and the like.

Finally, a whole new discipline, referred to as precision farming, or farming by the foot, has emerged. The application of pesticides, herbicides, and fertilizers is becoming an increasingly exacting science. Many farm implement manufacturers are producing variable-rate application equipment that is controlled by sophisticated electronics coupled to a sort of GIS. It has been shown that material input costs can be reduced by 40%, and yield enhancements of a similar magnitude can be expected. Furthermore, the harmful effects of the runoff of unneeded fertilizers can be mitigated. It is possible that the variable application of fertilizers might be legislated for this reason. GPS of course is central to the soil mapping to determine requirements and to the control of application vehicles.

Several firms offer products to guide airborne applicators of pesticides. These systems involve customized mapping routines to direct the pilot of crop duster swath by swath over a particular field. This allows the replacement of the flagperson, who would direct the pilot from the ground (a job in a very hazardous environment), with more accurate electronic guidance. This reduces the amount of overspray and can significantly decrease the amount of time and material used.

2.9 Handheld GPS

In general handheld GPS receivers are used for **absolute positioning** or for **relative positioning** using DGPS-services or WAAS/EGNOS signals. The positioning is realized using code pseudo-ranges. Moreover it is well known that some of the handheld receivers use phase-smoothed code for positioning. This means that the phase signal is available and may be used for Precise Differential GPS (PDGPS) positioning. Using GARMIN handheld receivers the phase and the code information may be transferred in real-time on a computer and stored in a RINEX file. Combining the RINEX file created by a handheld receiver with a RINEX file of another GPS site, the baseline could be solved in post-processing mode using phase pseudo-ranges. The paper describes the possibilities and limits of static and kinematic positioning using the handheld GPS phase information by using commercial post-processing software. More over the results of an antenna calibration that was carried through are presented. Accuracy analysis is the main part of the investigation. The analysis reveal that multipath and diffraction effects disturb the phase signals severely leading to a less reliable and accurate positioning result. In general the investigations show that the obtained static accuracy is well suitable for GIS applications. Under special conditions the accuracy reaches the real-time accuracy of precise geodetic receivers. Kinematic positioning does not lead to an accuracy increase due the available phase signal.

Garmin GPS units

GPS units made by Garmin International, Inc. (http://www.garmin.com/) are very popular for both research, recreational, and commercial work.

In addition, Garmin units tend to integrate well with various GIS software. Compare Garmin units, with side-by-side feature comparisons at http://www.garmin.com/outdoor/compare.jsp.

Compare Garmin eTrex family units, with side-by-side feature comparison at http://www.garmin.com/products/etrexVistac/.

Learn about Geocaching with Garmin:
http://www.garmin.com/specs/geocaching.pdf

GPS for Beginners Manual:
http://www.garmin.com/manuals/GPSGuideforBeginners_Manual.pdf

Chapter 3

Geoid

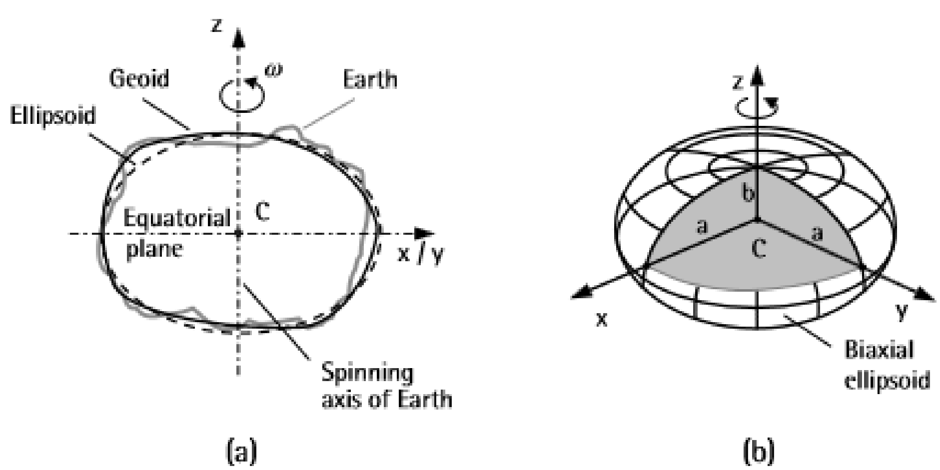
3.1 Datum (Datuum)

The fact that the topographic surface of the Earth is highly irregular makes it difficult for the geodetic calculations-for example, the determination of the user's location - to be performed. To overcome this problem, geodesists adopted a smooth mathematical surface, called the reference surface, to approximate the irregular shape of the earth (more precisely to approximate the global mean sea level, the geoid) [1, 2]. One such mathematical surface is the sphere, which has been widely used for low-accuracy positioning. For high-accuracy positioning such as GPS positioning, however, the best mathematical surface to approximate the Earth and at the same time keep the calculations as simple as possible was found to be the biaxial ellipsoid (Figure 14). The biaxial reference ellipsoid, or simply the reference ellipsoid, is obtained by rotating an ellipse around its minor axis , b [1]. Similar to the ellipse, the biaxial reference ellipsoid can be defined by the semi minor and semi major axes (a, b) or the semimajor axis and the flattening (a, f), where

$$f = 1 - (b / a)$$

An appropriately positioned reference ellipsoid is known as the geodetic datum [2]. In other words, a geodetic datum is a mathematical surface, or a reference ellipsoid, with a well-defined origin (center) and orientation. For example, a geocentric geodetic datum is a geodetic datum with its origin coinciding with the

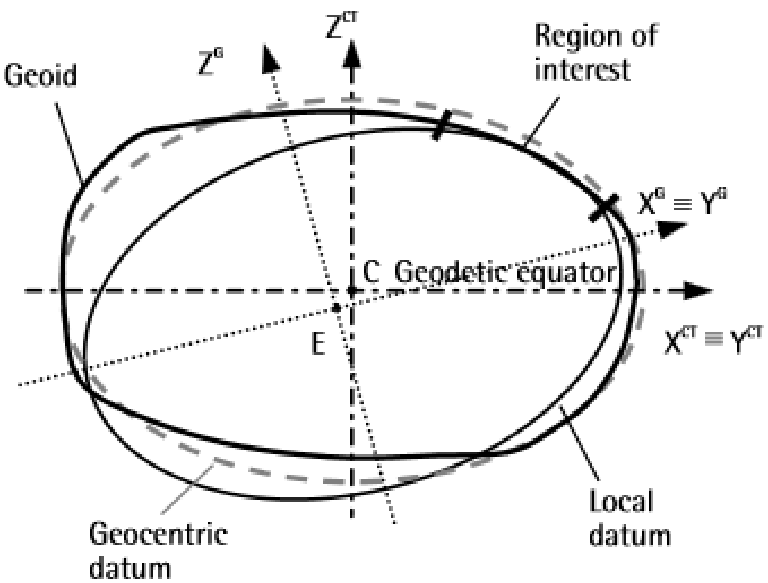
center of the Earth. It is clear that there are an infinite number of geocentric geodetic datums with different orientations. Therefore, a geodetic datum is uniquely determined by specifying eight parameters: two parameters to define the dimension of the reference ellipsoid; three parameters to define the position of the origin; and three parameters to define the orientation of the three axes with respect to the earth. Table 4.1 shows some examples of three common reference systems and their associated ellipsoids [2]. In addition to the geodetic datum, the so-called vertical datum is used in pactice as a reference surface to which the heights (elevations) of points are referred [1]. Because the height of a point directly located on the vertical datum is zero, such a vertical reference surface is commonly known as the surface of zero height. The vertical datum is often selected to be the geoid; the surface that best approximates the mean sea level on a global basis (see Figure 14 (a)). In the past, positions with respect to horizontal and vertical datums have been determined independent of each other [1]. However, with the advent of space geodetic positioning systems such as GPS, it is possible to determine the 3-D positions with respect to a 3-D reference system.



(Figure 14) : (a) Relationship between the physical surface of the Earth, the geoid, and the ellipsoid; and (b) ellipsoidal parameters.

3.2 Datum transformations

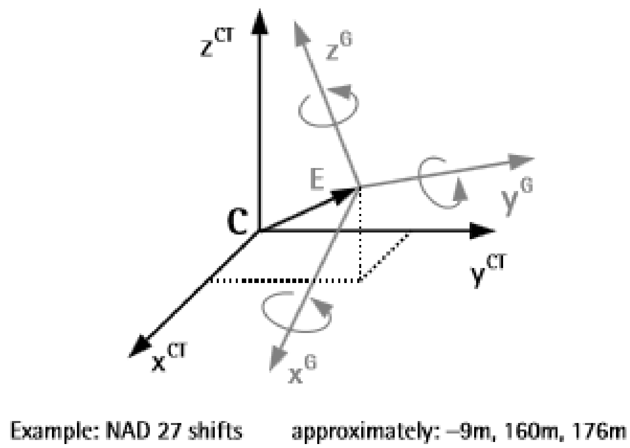
In the past , positions with respect to horizontal and vertical datums have been determined independent of each other [1]. In addition, horizontal datums were non geocentric and were selected to best fit certain regions of the world (Figure 15). As such, those datums were commonly called local datums. More than 150 local datums have been used by different countries of the world. An example of the local datums is the North American datum of 1927 (NAD 27).



(Figure 15) : Geocentric and local datums.

With the advent of space geodetic positioning systems such as GPS, it is now possible to determine global 3-D geocentric datums. Old maps were produced with the local datums, while new maps are mostly produced with the geocentric datums. Therefore, to ensure consistency, it is necessary to establish the relationships between the local datums and the geocentric datums, such as WGS 84. Such a relationship is known as the datum transformation (Figure 16).

NIMA has published the transformation parameters between WGS 84 and the various local datums used in many countries. Many GPS manufacturers currently use these parameters within their processing software packages. It should be clear, however, that these transformation parameters are only approximate and should not be used for precise GPS applications. In Toronto, for example, a difference as large as several meters in the horizontal coordinates is obtained when applying NIMA's parameters (WGS84 to NAD27) as compared with the more precise National Transformation software (NTv2) produced by Geomatics Canada. Such a difference could be even larger in other regions. The best way to obtain the transformation parameters is by comparing the coordinates of well-distributed common points in both datums.



(Figure 16) : Datum transformations.

3.3 horizontal and vertical datums

The concept of datums is very important in classical positioning. A datum is a surface of constant coordinate values. Two kinds of datums, vertical and horizontal, are used in practice. A vertical datum, a surface of zero height, is usually chosen to be the geoid, which is the equipotential surface of the earth's gravity field that best approximates mean sea level. Heights referred to the geoid, called orthometric heights H, are the heights one usually finds plotted on topographical maps. Orthometric heights are the heights used almost exclusively in surveying practice and elsewhere.

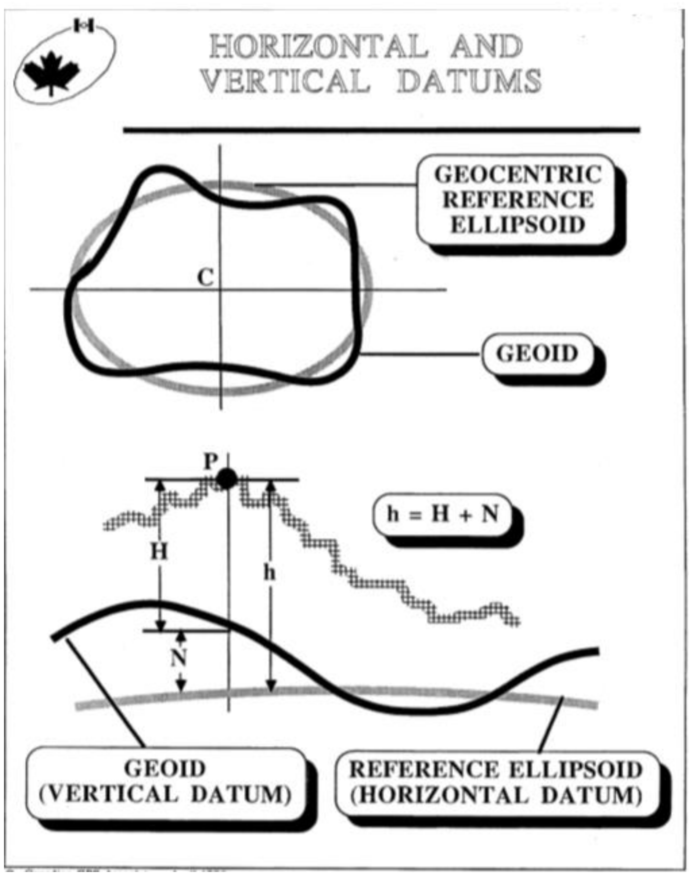
If the geoid is replaced with a biaxial ellipsoid, one can define geometrical heights h, also called heights above the (reference) ellipsoid, which have very little use in practice. However, their attraction is that they can be obtained directly from three-dimensional Cartesian coordinates of the point of interest, provided the location and orientation of the reference ellipsoid in the Cartesian coordinate system is known [Van1cek and Krakiwsky, 1986]. The equation that links the two kinds of heights is shown in the figure, where the elevation N of the geoid above the reference ellipsoid is usually called the geoidal height. Globally, the absolute value of N with respect to the best fitting geocentric reference ellipsoid is almost everywhere smaller than 100 meters.

Whereas the use of the ellipsoid as a reference for heights is impractical for many tasks, its use as a reference for horizontal coordinates, latitude p and longitude A, is widespread. This is why such reference ellipsoids are ·commonly called horizontal datums. Many horizontal datums (both geocentric and non-geocentric) are used throughout the world.

Clearly, if we were happy describing positions by Cartesian coordinates in a system such as, for example, the Conventional Terrestrial system, the use of both vertical and horizontal datums could be abandoned. This is, conceptually, the case with positioning by satellites. However, in practice, satellite-determined Cartesian coordinates must usually be transformed to p, A, and H. This transformation, as stated above, requires know ledge of:

• the location and orientation with respect to the Cartesian coordinate system of the horizontal datum selected,

• the height of the geoid above the horizontal datum.

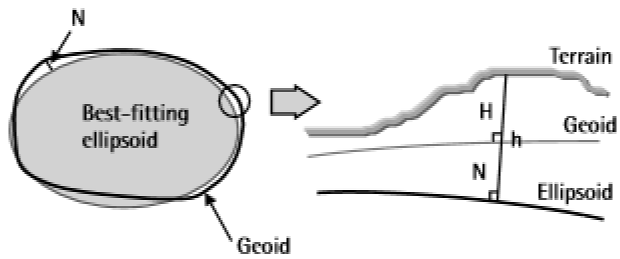


(Figure 17) : horizontal and vertical datums.

3.4 Height systems

The height (or elevation) of a point is defined as the vertical distance from the vertical datum to the point (Figure 18). The geoid is often selected to be the vertical datum [1]. The height of a point above the geoid is known as the orthometric height. It can be positive or negative depending on whether the point is located above or below the geoid. Because they are physically meaningful, orthometric heights are often needed in practice and are usually found plotted on topographic maps [1]. In some cases, such as the case of GPS, the obtained heights are referred to the reference ellipsoid, not the geoid (Figure 18). Therefore, these heights are known as the ellipsoidal heights. An ellipsoidal height can also be positive or negative depending on whether the point is located above or below the surface of the reference ellipsoid. Unfortunately, ellipsoidal heights are purely geometrical and do not have any physical meaning. As such, the various Geomatics instruments (e.g., the total stations) cannot directly sense them.

The geoid-ellipsoid separation is known as the geoidal height or undulation (Figure 18). This distance can reach up to about 100m, and it can be positive or negative depending on whether the geoid is above or below the reference ellipsoid at a particular point [3]. Accurate information about the geoidal height leads to the determination of the orthometric height through the ellipsoidal height, and vice versa. Geoid models that describe the geoidal heights for the whole world have been developed.



(Figure 18) : Height systems.

Unfortunately, these models do not have consistent accuracy levels everywhere, mainly because of the lack of local gravity data and the associated height information in some parts of the world [3]. Many GPS receivers and software packages have built-in geoid models for automatic conversion between orthometric and ellipsoidal heights. However, care must be taken when applying them, as they are usually low-accuracy models.

Field work:

In the beginning, we collected the measured points which counted 309 points, but 110 points were chosen for measuring by the GPS,

The reason behind using this 110 is: its good distribution, Accessibility, Inside Riyadh city, Strong signal at each point, Enough number to generating a geoid model with small error and 9 points for check

The duration of calculating coordinates by GPS is one second 60 times for each point, and about the satellite navigation technique used is Real Time Kinematic, or RTK “fixed”

RTK data collection can be “fixed” or “float,” with different levels of precision, If a sufficient number of satellites are visible, RTK can provide a fixed position, within a fraction of an inch. If insufficient satellites are visible, RTK can provide only a float solution, with a precision of a few inches.

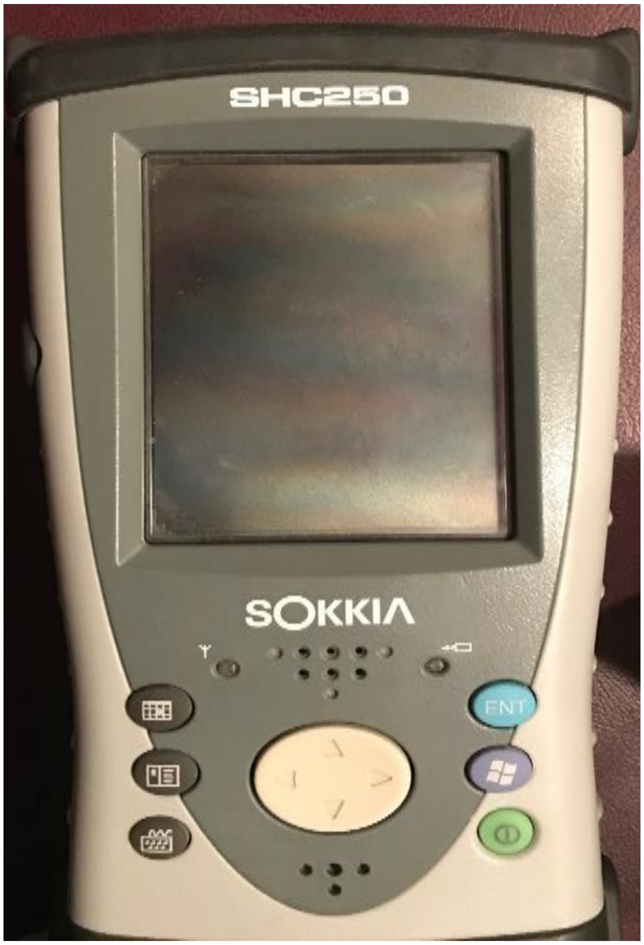
(Figure 19) A sample of MOMRA’s point

(Figure 20) Location of MOMRA's point number 120002

The GPS devices used TOPCON FC-250, GR3 DIGITAL UHF, SOKKIA SHC250, GRX1

(Figure 21) TOPCON FC-250

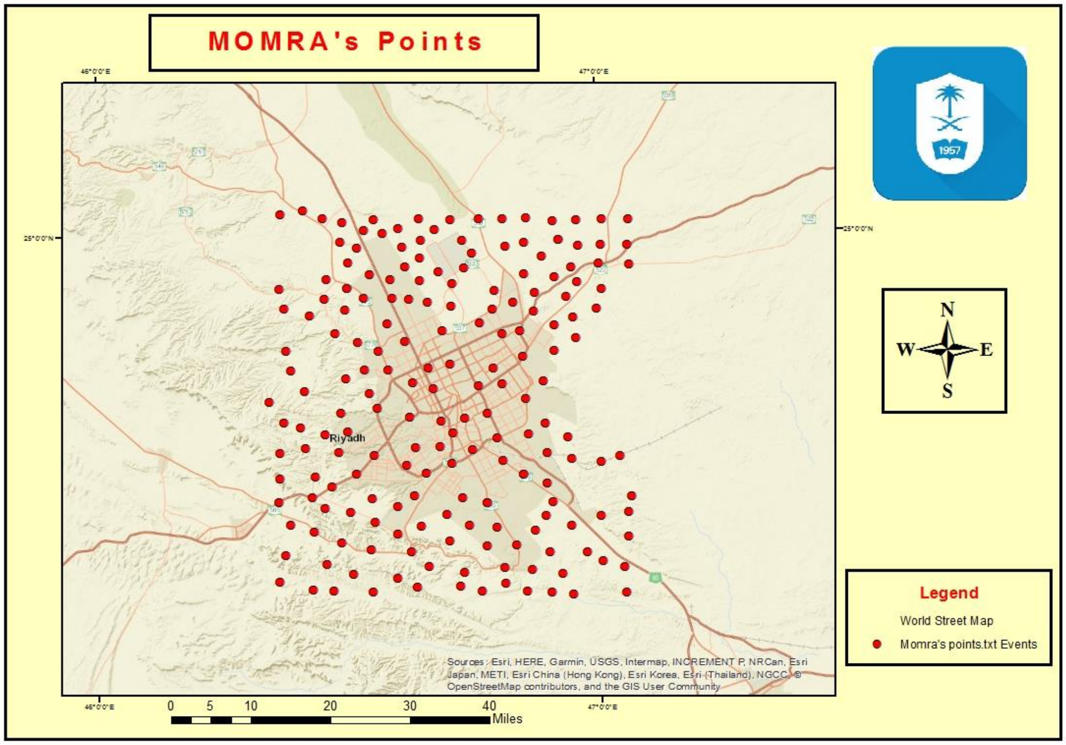
(Figure 22) TOPCON GR3 DIGITAL UHF



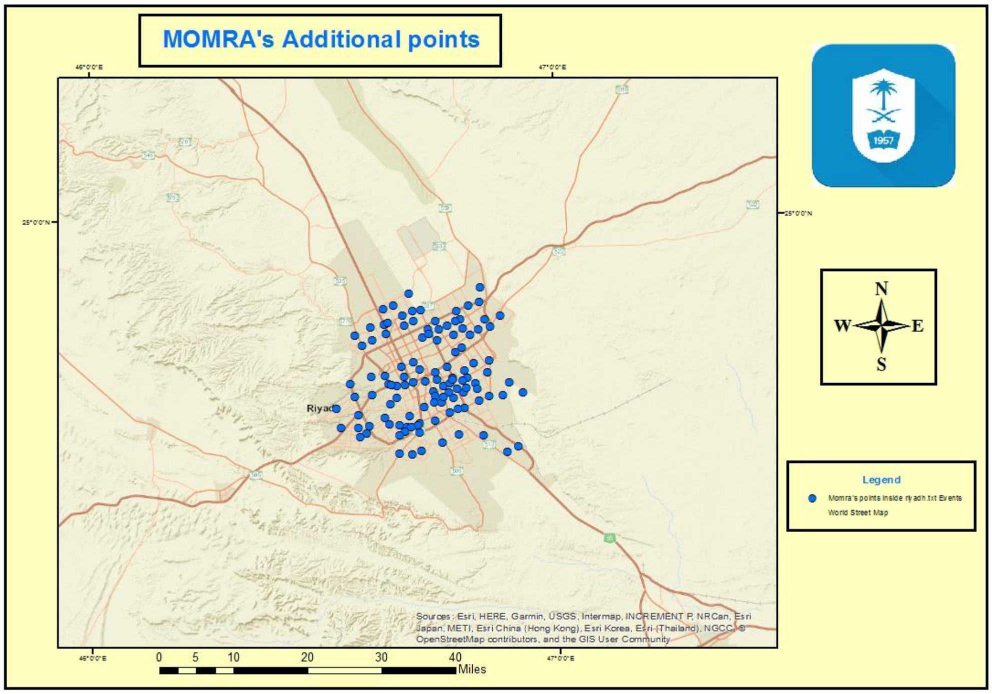
(Figure 23) SOKKIA SHC250

(Figure 24) SOKKIA GRX1

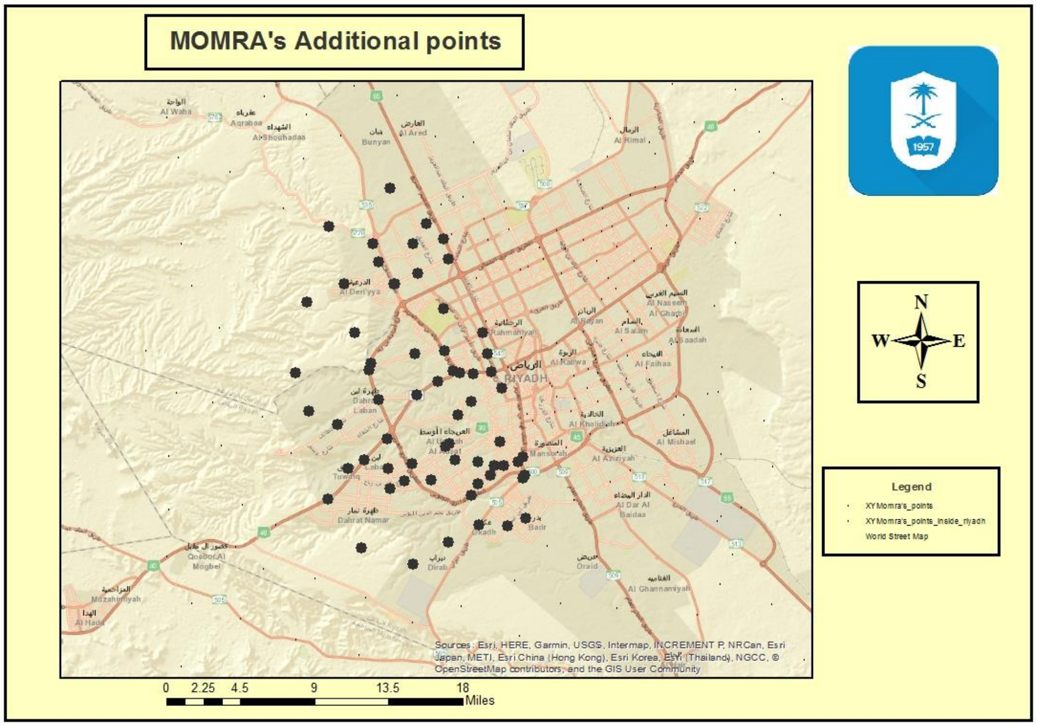
Area of interest (AOI):



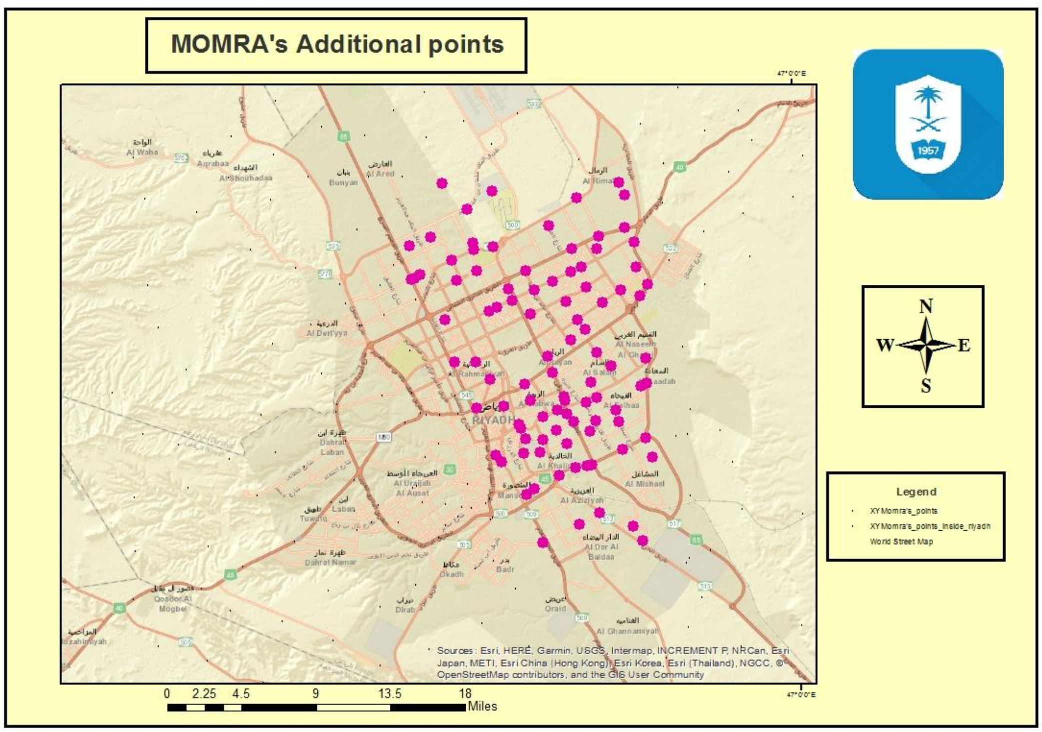
(Figure 25) distribution of the control points in Riyadh city



(Figure 26) distribution of the additional control points inside Riyadh city



(Figure 27) The points in left side of Riyadh city to be used in this project



(Figure 28) The points in right side of Riyadh city to be used by another group

Calculation and result

First of all ; the equations of the ellipsoid (WGS 84)

$X = N \cos \Phi \cos \lambda$

$Y = N \cos \Phi \sin \lambda$

$Z = N (1 - e^2) \sin \Phi$

Secondly ; the equations of the ellipsoid (WGS 84) after moving it to be touching the Geoid

$X + \Delta x = (N + h') \cos \Phi \cos \lambda$

$Y + \Delta y = (N + h') \cos \Phi \sin \lambda$

$Z + \Delta z = [N (1 - e^2) + h'] \sin \Phi$

so , if we subtract the second equations from the first equations it will be :

$\Delta x = h' \cos \Phi \cos \lambda$

$\Delta y = h' \cos \Phi \sin \lambda$

$\Delta z = h' \sin \Phi$

$h' = h^{GPS} - h^{handheld}$ Whereas the average of $h' = 85.31225$ m

$\Delta x = -71.8613382$ m

$\Delta y = 28.1020487$ m

$\Delta z = -35.650585$ m

But there are other variables and they are Δa and Δf , they will be = 0 because we will not change the shape of the ellipsoid just moving it in X , Y and Z direction

At the end ; the handheld GPS settings will be replaced to these variables :

$\Delta x = -71.8613382$ m	$\Delta a = 0$
$\Delta y = 28.1020487$ m	$\Delta f = 0$
$\Delta z = -35.650585$ m	

Explanation the symbols

X x-axis Y y-axis Z z-axis

Δ x the distance form the original ellipsoid to the new ellipsoid in x-axis

Δ y the distance form the original ellipsoid to the new ellipsoid in y-axis

Δ z the distance form the original ellipsoid to the new ellipsoid in z-axis

Δ f Flatness coefficient

Δ a scale factor

h’ the different between the orthometric height (altitude) and the observed height via Handheld GPS

h^{GPS} the orthometric height (altitude)

$h^{handheld}$ the observed height via Handheld GPS

Φ (Phi) the Latitude in degree

λ (Lambda) the Longitude in degree

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Appendix :

1- Excel file ; Two sheets
   a. the data of the control points
   b. the data of the four control points with calculation
2- Link ; map of the control points